PRELIMINARY RESULTS ON A SEARCH FOR NEUTRINOS FROM THE CENTER OF THE EARTH WITH THE BAIKAL UNDERWATER TELESCOPE

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Abstract

The deep underwater Cherenkov neutrino telescope NT-200 is currently under construction at lake Baikal. Its first stage NT-36 consisting of 36 optical modules has operated over 2 years since April 1993 till March 1995. Here we present a method to search for nearly vertical upward going muons from neutralino annihilation in the center of the Earth. We present preliminary results obtained from experimental data taken with the NT-36 array in 1994.

1. Introduction

An attractive way to search for cold dark matter is the detection of high-energy neutrinos produced by neutralino annihilation in the Earth and in the Sun. The Baksan and the Kamiokande collaboration have presented stringent limits on the upgoing muon flux initiated by neutralinos in the Earth[1,2]. Further progress is possible with underwater (BAIKAL, DUMAND, NESTOR) and under ice (AMANDA) experiments which will have effective areas of 2-10 thousand square meters. The first

large deep underwater detector for muons and neutrinos, NT-200, is currently under construction in the lake Baikal. The first stage of the detector consisting of 36 optical modules (NT-36) successfully has operated over 2 years since 1993 till 1995.

The first attempt for an indirect search for neutralinos with an underwater experiment has been performed on the base of experimental data taken during 1994 with the detector NT-36.

2. Detector

The Baikal Neutrino Telescope[3] is being deployed in the Siberian Lake Baikal, about 3.6 km from the shore at the depth of 1.1 km. It will consist of 192 optical modules (see Fig.1). The 7 arms of the umbrella-like frame carrying the detector, each 21.5 m in length, are at the height of 250 m above the bottom of the lake. The optical modules are grouped in pairs along the strings, directed alternatively upward and downward. The distance between pairs looking face to face is 7.5 m, while pairs arranged back to back are 5 m apart. The pulses from two PMTs of a pair after 0.3 *p.e.* discrimination are fed to a coincidence circuit with 15 ns time window. A PMT pair defines a *channel* with its output denoted as *local trigger* (or simply *hit*). A *muon-trigger* is formed by the requirement of ≥ 3 hits within a time window of 500 ns. For such events, amplitude and time of all hit channels are digitized and sent to shore.

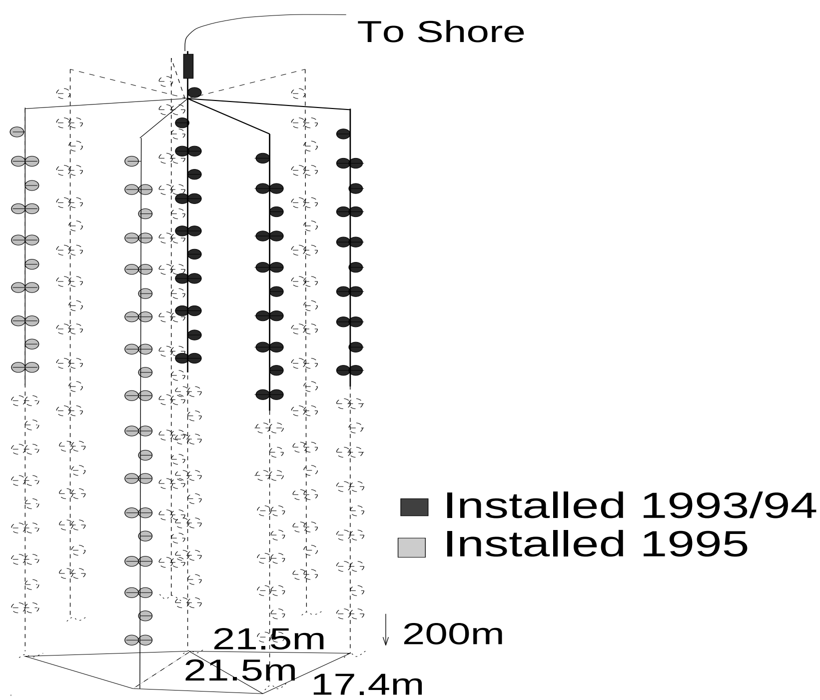

Figure 1: Schematical view of the planned NT-200 detector. NT-36 components operating since April 1993 are in black, additional modules deployed in March 1995 in grey.

In April 1993, NT-36 started data taking and operated till March 1995. There have been 6 PMT pairs along each of 3 strings of NT-36. The numbering is, from

top to bottom: 1(up-looking), 2(down-looking), 3(up), 4(down), 5(up), 6(down) with PMT orientations which are given in the parenthesis for 1994 NT-36 modification.

3. Method

Our search for possible high-energy neutrino events resulting from dark matter annihilation in the center of the Earth is based on the analysis of the experimental data with respect to upward-going muons within a cone of about 15 degree half-aperture around the opposite zenith.

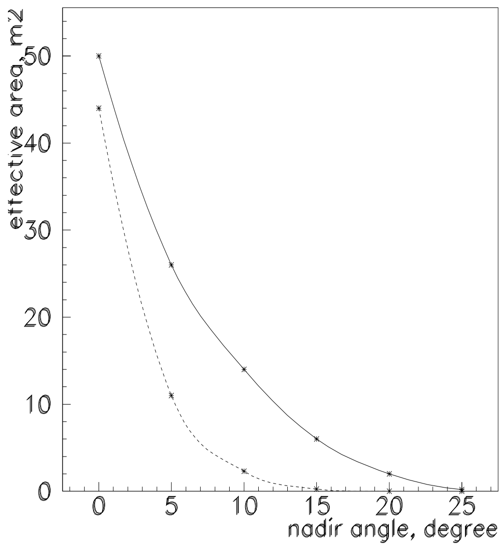

Figure 2: The single string effective area vs. muons zenith angle. Solid and dashed lines correspond to $dt = 13$ and 5 ns, respectively.

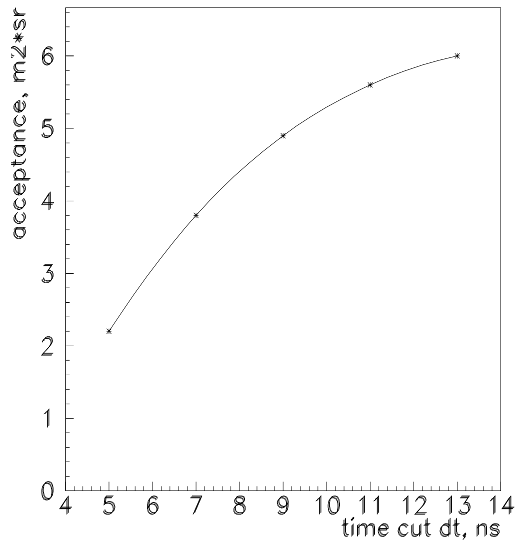

Figure 3: The single string acceptance vs. time cut values dt.

In contrast with our standard reconstruction strategy, which supposes ≥ 6 hits at ≥ 3 strings (necessary for full spatial reconstruction[4]), we did not perform a reconstruction at all, but applied cuts, which effectively reject all events with the exception of nearly vertically moving upward muons triggering exclusively channels along the string. In our case this method works well since the tracks of the objects searched for have nearly the same vertical orientation as the strings. The following off-line trigger conditions were used:

#1 three down-looking and at least one up-looking channels at one string exclusively must be hit;

#2 time differences of any two hit channels i and j must obey the inequality

$$abs((t_i - t_j) - (T_i - T_j)) < dt$$

- where $t_i(t_j)$ is an experimental time of channel $i(j)$, $T_i(T_j)$ is the "theoretical" time expected for minimal ionizing, up-going vertical muons and dt is a time cut ($dt = (5, 7, \ldots, 13, \ldots)$ns);

#3 the minimum value of amplitude asymmetries for all pairs of alternatively directed (up/down) hit channels must obey the inequality $dA_{ij}(down-up)|_{min} > 0.3$, where

$$dA_{ij}(down-up) = (A_i(down) - A_j(up))/(A_i(down) + A_j(up)),$$

$A_i(down)(A_j(up))$ - amplitude of channel $i(j)$ looking downward(upward);

#4 the maximum value of amplitude asymmetries for all pairs of down-looking hit channels must obey the inequality $dA_{ij}(down-down)|_{max} < 0.7$ where

$$dA_{ij}(down-down) = abs(A_i(down) - A_j(down))/(A_i(down) + A_j(down)).$$

The effective area and acceptance of NT-36 for off-line trigger conditions #1–#4 obtained from MC simulations are presented in Fig.2 and Fig.3.

4. Results

Our analysis is based on the data taken during the time period April 8 to November 9, 1994. This corresponds to 150 days of detector live time. Upward-going muon candidates were selected from a total of $7.72 \cdot 10^7$ events recorded during this period by the muon-trigger ≥ 3. Eight events fulfill the earlier defined off-line trigger conditions #1–#3 with $dt = 13$ns. Seven events of this sample have a value of maximum asymmetry for down-looking channels $dA_{ij}(down-down)|_{max} > 0.8$ and have been classified as showers, generated by downward going atmospheric muons. Only 1 event fulfills all off-line trigger conditions #1–#4 with $dt = 13$ns. It is 6 June 1994 event. Experimental and "theoretically" expected (in parenthesis) values of time differences for hit channels in this event are presented in Tab. 1. The values of amplitude asymmetries for up-down and down-down looking channel combinations are presented in Tab. 2.

Table 1. Experimental and "theoretically" expected (in parenthesis) values of time differences between hit channels i, j.

i/j	ch.4 (down)	ch.5 (up)	ch.6 (down)
ch.2 (down)	44ns (42ns)	64ns (67ns)	87ns (84ns)
ch.4 (down)	—	21ns (25ns)	43ns (42ns)
ch.5 (up)	—	—	22ns (17ns)

Table 2. The values of amplitude asymmetry for hit channels i, j.

i/j	ch.4 (down)	ch.5 (up)	ch.6 (down)
ch.2 (down)	0.05	0.64	0.26
ch.4 (down)	—	0.66	0.30
ch.5 (up)	—	—	0.45

The time pattern of such event might be generated by a shower below the detector or by a nearly horizontal muon (being rare events themselves). However, it is

difficult to imagine that something else but an upward going muon could generate the observed amplitude pattern in combination with the time one. Thorough MC calculations in order to ascertain the background due to fake events are underway. Some data corrections are still necessary concerning sedimentation, time stability of PMTs sensitivity etc. But our preliminary estimations yield the signal-to-fake ratio of the order of unity for this kind of events. Therefore, we consider the event as the first promising neutrino candidate.

The expected number for events generated by upward going muons from atmospheric neutrinos was calculated as 0.4 for runtime 0.41 year. Then, regarding the only neutrino candidate as an atmospheric neutrino event, an 90 % CL upper limit of $2.5 \cdot 10^{-13}$ (muons/cm^2/sec) in a cone with 15 degree half-aperture around the opposite zenith is obtained for upward going muons generated by neutrinos due to neutralino annihilation in the center of the Earth. This limit corresponds to muons with energies greater than threshold energy $E_{th} \approx 6$ GeV, defined by the 30m string length.

5. Conclusions

We have presented the preliminary analysis of experimental data taken with the underwater detector NT-36 in order to study the capability of the indirect search for dark matter with Baikal experiment. The first promising candidate for an upward going muon was identified. An upper limit for the up-going muon flux has been obtained. This is still an order of magnitude higher than the limits obtained by Baksan and Kamiokande. The effective area of NT-36 for nearly vertical up-going muons fulfilling our off-line trigger conditions is $S_{eff} = 50$ m^2/string. A rough estimation of the effective area of the full-scale Baikal neutrino telescope NT-200 (comprising eight twice longer strings) for detection of upward going muons gives the value $S_{eff} \approx$ 400-800 m^2.

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